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The selection of the logistics center location based on MCDM/A methodology

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Abstract

The paper presents the first stage of the MCDM/A-based two-stage procedure resulting in the selection of the most desirable location of the logistics centre. In the first stage, the macro-analysis of the regions is carried out and multiple criteria evaluation of their technological, infrastructural, economic, social and environmental potential is performed. The decision problem is formulated as a multiple criteria ranking problem. The considered variants – regions are ranked from the best to the worst – in terms of their suitability for locating the logistics centre within their boundaries – with the application of the MCDM/A method, called Electre III/IV. The variants and a consistent family of criteria are defined, the decision maker's preferences are modelled and the results of computational experiments are demonstrated.

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Keywords: logistics center, location problem, MCDM/A methodology, Electre III/IV method;

1. Introduction

The "location problem"(Owen, Daskin, 1998; Farahani, Hekmatfar, 2009) consists in determining a proper placement of an infrastructural component (ground, site, facility) in a considered area, taking into account the decision maker's (DM's) preferences and existing constraints. It has a universal character and may refer to different categories of sites/facilities (Farahani, Hekmatfar, 2009; Farahani, et al, 2010). Many mathematical formulations

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and approaches to solving this problem have been reported, including: mathematical programming (Klose, Drexl, 2005), evaluation and ranking of considered sites (Özcan, et al, 2011; Korpelaa, Tuominen, 1996; Awasthi, et al, 2011). The location problem plays also a crucial role in logistics, where it refers to finding the most desirable location of logistics facilities (see section 2).

One of the typical logistics location problems refers to the proper placement of logistics centers (Van Thai, Grewal, 2005; Kayikci, 2010). The logistics center (LC) is a separate entity operating in a secured area, within which all logistics activities (transportation and forwarding, material handling, warehousing, inventory management, cross-docking, intermodal trans-shipment, physical distribution of goods) are carried out on a commercial basis. In the modern concepts of 3PL and 4PL (Rushton, et al, 2006) LC plays an important role of logistics service integrator that provides customers with a comprehensive, high quality service and connects all possible transportation modes (road, rail, water and air).

The authors of this paper belong to a narrow group of researchers (e.g. Daganzo, 1996), who have discovered that the LC location problem may and should be considered as a two-level, hierarchical problem. At the first, upper level the macro-analysis of the wider areas – macro-regions should be carried out to determine their overall potential and suitability for placing the LC on their territory. At the second, micro-level, the microscopic analysis is carried out to define the most appropriate, specific locations of the LC within the region previously selected at level 1. In this paper the authors consider the 1st level of the LC location problem, only. They carry out the macroscopic analysis of selected regions and determine the most desirable area/district to carry out the logistics activity. Based on methodological principles of multiple criteria decision making/aiding (MCDM/A) (Figueira, et al, 2005; Roy, 1990a; Vincke, 1992; Zak, 2005; Zak, 2011) and their application in logistics (Drezner, Hamacher, 2002; Awasthi, et al, 2011; Özcan, et al, 2011) the authors formulate the regions' selection problem as a multiple criteria ranking problem and solve it with the application of the Electre III/IV method.

The paper is composed of six sections. The first one includes introductory remarks and the background of the LC location problem. In the second section the literature review concerning the location problem of logistics facilities is presented. Third section describes the methodology of MCDM/A. In the next section, the decision problem focused on the evaluation of macro-regions, being the first component of the LC location problem, is formulated. The variants – regions, evaluation criteria and DM's preferences are defined in this section. The fifth section contains the results of computational experiments, while the last one presents conclusions and further research directions.

2. Location problem in transportation and logistics

Location problem is a widely discussed topic in transportation and logistics (Owen, Daskin, 1998; Chen, et al, 2007; Daganzo, 1996; Özcan, et al, 2011) and refers to the selection of specific locations of such facilities as (Van Thai, Grewal, 2005; Drezner, Hamacher, 2002; Fierek, et al, 2007; Church, Murray, 2009; Farahani, Hekmatfar, 2009): warehouses, distribution centres, transportation hubs, passenger and cargo terminals, material inventory and cross – docking areas, parking lots, passengers' interchange terminals and many others. In the majority of cases the location problem of logistics facilities has a strategic character and the generated solutions/decisions have a long term impact.

In general, the logistics-oriented location problems can be classified based on different allocation criteria into the following categories (Farahani, et al, 2010; Klose, Drexl, 2005):

- The **applied approach** to the formulation of the decision problem (ranking and mathematical programming – optimization problems).
- The proposed **number of evaluation criteria** (single and multiple - objective location problems).
- The proposed approach to **handling risk and uncertainty (**deterministic and non-deterministic problems).
- The **topographic character of the network** and the resulting approach to selecting the location of facilities (continuous and discrete location problems).

- The **number of objects/locations** under consideration (single and multiple facility location problem).

Klose and Drexl (2005) present a comprehensive analysis of different logistics-oriented location problems, formulated as mathematical programming (optimization) problems. Farahani, et al (2010) present a review of location problems formulated as multiple criteria decision problems.

It is worth emphasizing that, to the best of the authors knowledge, a multistage, multiple criteria location analysis for logistics centre (LC) have not been reported in the literature. Thus, the proposed approach seems to be original and corresponds to the current agenda of investigations in this area.

3. The MCDM/A methodology

3.1. Introduction to MCDM/A

MCDM/A is a field of study focused on the development of mathematical procedures and advanced computer-based methods that support the DM in solving multiple criteria decision problems (Figueira, et al, 2005; Vincke, 1992). A multiple criteria decision problem is a situation in which, having defined a set of actions/variants/solutions *A* and a consistent family of criteria *F* the DM tends to (Vincke, 1992; Zak, 2005):

a) determine the best subset of actions/variants/solutions in *A* according to *F* (choice problem),
b) divide *A* into subsets representing specific classes of actions/variants/solutions, according to concrete classification rules (sorting problem),
c) rank actions/variants/solutions in *A* from the best to the worst, according to *F* (ranking problem).

Based on the above quoted definition one can easily determine major components of each multiple criteria decision problem, i.e., a set of actions/variants/solutions *A* and a consistent family of criteria *F* (Roy, 1990a; Vincke, 1992; Figueira, et al, 2005).

In the multiple criteria – based decision making processes different computer-based MCDM/A methods are used. In contrast to the classical techniques of operations research, multiple criteria methods do not yield "objectively best" solutions. Instead of that they search for compromise solutions that take into account the trade-offs between criteria and the DM's preferences. The MCDM/A methods can be classified according to several criteria, including **three major ones:** the overall objective of the decision process (Zak, 2005), the moment of the definition of the DM's preferences (Zak, 2005) and the manner of the preference aggregation (Roy, 1990a; Vincke, 1992). Based on **the first division criterion** one can identify the following multiple criteria decision making methods (Zak, 2005): choice (optimization) methods; classification (sorting) methods; ranking methods. With respect to **the second division criterion** three categories of methods are identified (Zak, 2011): methods with an a'priori defined preferences (e.g., Electre I-IV, Promethee I and II); methods with an a'posteriori defined preferences (e.g., PSA method); interactive methods (e.g., STEM, VIG, LBS). According to **the third classification criterion** one can distinguish: the methods of American inspiration, based on the utility function (e.g., AHP, UTA); the methods of the European/French origin, based on the outranking relation (e.g., Electre I-IV, Promethee I-II).

Based on the suggestions of Roy (1990a), Vincke (1992) and Zak (2005) one can distinguish the following major stages of the solution procedure of the multiple criteria decision problem:

- Identification and verbal description of the decision problem; recognition of its category and definition of major participants of the decision process.
- Mathematical formulation of the decision problem, including:
    - definition of the set of variants *A,*
    - construction of the consistent family of criteria *F*,
- Modeling of the DM's preferences,
- Selection of the most suitable MCDM/A method to solve the considered decision problem.
- Running computational experiments with an application of the selected MCDM/A method. Aggregating the DM's preferences using a specific model of synthesis.

According to the MCDM/A methodology, the following major bodies participate in the above described solution procedure, often called a decision making process: the decision maker (DM), the analyst and interveners/stakeholders (Figueira, et al, 2005; Vincke, 1992).

In this paper the above presented solution procedure is applied and the most representative multiple criteria ranking method of the European school of MCDM/A, ELECTRE III/IV, is used to evaluate the alternative regions constituting the areas for placing the LC on their territory. A short description of the method is presented below.

3.2. Basic characteristics of Electre III/IV method

ELECTRE III/IV method belongs to a family of ELECTRE methods, proposed by Roy (1990b) and it is based on the binary outranking relation (Roy, 1990a; Vincke, 1992). In this method, the basic set of data is composed of the following elements: a finite set of variants *A*, a family of criteria *F*, and the preferential information submitted by the DM. The preferential information is defined in the form of criteria weights - *w* and the indifference - *q*, preference - *p* and veto - *v* thresholds (Roy, 1990b). The thresholds define the following intervals of preference between variants on each criterion: indifference (up to *q*), weak preference (between *q* and *p*), (strong) preference (between *p* and *v*) and incomparability (beyond *v*). Variants *a* and *b* are considered indifferent if the difference between their evaluations *f(a)* and *f(b)* on a specific criterion is so small (smaller than *q*) that the DM can not make any distinction between variants. Variant *a* is weakly preferred against variant *b* if the difference between their evaluations *f(a)* and *f(b)* on a specific criterion is noticeable to the DM (between *q* and *p*) but he/she is hesitant to prefer one of them. Variant *a* is strongly preferred against variant *b* if the difference between their evaluations *f(a)* and *f(b)* on a specific criterion is substantial to the DM (between *p* and *v*) and he/she is convinced that a is preferred to *b*. Variants *a* and *b* are incomparable if the difference between their evaluations *f(a)* and *f(b)* on a specific criterion is so large (larger than *v*) that the DM cannot consider them as comparable objects.

The outranking relation in the ELECTRE III/IV method is built on the basis of the so called concordance and discordance tests. In the concordance test a concordance matrix, composed of the global concordance indicators *C(a,b),* is constructed. In the discordance test, a discordance index $d_j(a,b)$ for each criterion *j* is calculated. The outranking relation indicates the extent to which "*a* outranks *b*" overall. This relation is expressed by the degree of credibility *d(a,b),* which is equivalent to the global concordance indicator *C(a,b)* weakened by the discordance indexes $d_j(a,b)$. The values of *d(a,b)* are from the interval [0,1]. Credibility $d(a,b) = 1$ if and only if the assertion *a S b* ("a outranks b") is well founded, $d(a,b)= 0$ if there is no argument in favor of *a S b* (not a *S b* – "a does not outranks b"). The definition of *d(a,b)* results in the construction of the credibility matrix based on which the method establishes two preliminary rankings (complete preorders) using a classification algorithm (distillation procedure). During this procedure one can obtain a descending and an ascending preorder. In the descending distillation the ranking process starts from the selection of the best variant, which is placed at the top of the ranking. In the ascending distillation the variants are ranked in the inverse order. The final ranking is generated as an intersection of the above mentioned complete preorders. It can be presented either in the form of the ranking matrix or in the form of the outranking graph. The following situations can be distinguished there: indifference *(I),* preference *(P),* lack of preference *(P~)* and incomparability *(R).*

4. Formulation of the regions' selection problem

4.1. Problem description and the applied solution procedure

The considered decision problem consists in selecting the most desirable area/region for placing the LC on its territory. It is formulated as a multiple criteria ranking problem and involves a multiple dimensional evaluation of the considered regions, including different: technical, economic, social, market-oriented and environmental aspects. As previously described the decision problem constitutes the first component of the LC location problem.

The decision under consideration is important for many groups of interest (stakeholders), including: local community (residents), local business environment – companies and business units, including logistics service operators. The decision concerning the selection of the LC location and the associated with it choice of regions/areas is made by an investor or a group of investors. In the decision process the DM has to take into account contradictory interests of the above mentioned stakeholders. He/she must balance certain trade-offs and search for the most satisfactory – compromise solution. The decision of the investor is also very important for local authorities whose overall interest consist in pulling money into the region, contributing to the region's development and creating new jobs and positions.

Due to the above mentioned features of the regions' ranking problem it has a multiple objective character. Thus, a universal procedure of solving the multiple criteria decision problem (Roy, 1990a; Zak, 2005) has been applied and customized to solve it (see section 3.1). The decision problem has a generic character and has been formulated and solved in universal terms. The presented case study refers to local conditions in Poland.

4.2. Definition of variants – potential macro regions

The considered variants (described below) have been defined as 10 macro-regions, distributed all over Poland (see Figure 1) and representing potential areas for placing the LC-s on their territory. Each variant covers an area of 12 – 44 thousand km^2 and has a population of 2,5 – 5,5 mln people. The variants are denominated by abbreviations corresponding to their sequential numbers and geographic locations, e.g. variant 1- V_1 – NW (north-western).

Variant 1 (V_1 – NW) is located in the North-Western part of Poland. Total area of the region is close to 37 000 km^2 and its population amounts to 2,7 mln people. The region is characterized by close to average level of economic development, represented by an annual GDP per capita of $10 755. It is considered to be investment – attractive with the lowest unit cost of investment ($392/m^2) and the average level of the area of Special Economic Zones (SEZ). Other advantages of the region are its: environmental friendliness and high traffic safety. The weaknesses of variant 1 are: relatively poor condition of the transportation infrastructure and serious social problems, including very high unemployment rate of 16,5%. The region is not attractive from a logistics point of view. The volume of all transported goods is very low and falls below 10 bln tkm.

Variant 2 (V_2 - N) is located in the Northern part of Poland. Total area of the region is slightly above 36 000 km^2 and its population amounts to 4,3 mln people. The region is again characterized by slightly lower than average level of GDP per capita ($10 953) and it is featured by a certain logistics attractiveness. The overall volume of all material flows (transported goods) exceeds in this region 13 bln tkm. Variant 2 is not an investment friendly area, featured by high unit cost of investment ($421/m^2) and lower than average area of SEZ. The transportation infrastructure, both road and rail, is underdeveloped in this region. Variant 2 has high unemployment rate of 14,0%. Similarly to variant 1, it is environmentally friendly and satisfactory in terms of traffic safety.

Variant 3 (V_3 - NE) is located in the North-Eastern part of Poland. The region is famous of its beautiful green, rural areas, tourist attractions and outstanding lake district. Its total area equals 44 000 km^2 and its population is 2,6 mln people. This region is very poor in terms of its economic and infrastructural characteristics. It is characterized by low level of GDP (less than $9000) and the lowest volume of transported goods, among compared areas (less than 7 bln tkm). The transportation infrastructure of the region is in a very poor condition. The region faces severe social problems, including the highest unemployment rate of 16,8%. On the other hand it is very attractive from an investor point of view because it is featured by very low unit cost of investment ($395/m^2). Unfortunately, it does not possess many SEZ areas. The region is considered to be environmentally friendly and traffic safe.

Variant 4 (V_4 - CW) is located in the Central-Western part of Poland. The region is famous of a tradition of "good work", high competitiveness and entrepreneurship. Total area of the region is close to 30 000 km^2 and its population amounts to 3,4 mln people. The region is characterized by higher than average level of GDP per capita ($12 580) and an average level of logistics attractiveness. The volume of all material flows (transported goods) is close to 12 bln tkm. The region is not investment attractive. It is featured by the highest unit cost of investment ($443/m^2) and a very low level of SEZ areas. The transportation infrastructure of the region represents an average level, while the unemployment rate in the region belongs to the lowest in the country (9,2%). The region is attractive in terms of environmental friendliness and traffic safety.

Variant 5 (V_5 - C) is located in the Central part of Poland. Total area and population of the region are above 18 000 km^2 and close to 2,5 mln people, respectively. The region is considered to be "an average" in many terms. It is featured by an average: level of the GDP per capita ($11 314), development of the transportation infrastructure, unit cost of investment ($402/m^2), unemployment rate of 11.9%, environmental friendliness and traffic safety. Surprisingly (taking into account the region's central location), it is featured by a very low volume of all transported goods (close to 8 bln tkm) and low level of SEZ areas.

Variant 6 (V_6 - CE) is a business oriented region, located in the Central-Eastern part of Poland. Its total area is 35 500 km^2 and its population amounts to 5,2 mln people. This region is characterized by the highest level of GDP per capita of $19 000 and the lowest unemployment rate of 9%. It is also attractive from the logistics point of view. The overall volume of all material flows (goods) moving through the region is close to 16 bln tkm. Clear disadvantages of variant 6 are: very high unit cost of investment ($424/m^2), the lowest level of SEZ areas and high number of road accidents. Both the region's development of transportation infrastructure and environmental friendliness are at the average levels.

Variant 7 (V_7 - E) is located in the Eastern part of Poland. The region is a good example of the Polish "Eastern wall", which for historical reasons always belonged to the least developed country's areas. Total area of the region is around 37 000 km^2 and its population amounts to 3,4 mln people. The region is characterized by the lowest level of GDP per capita ($8 904) and lower than average volume of all material flows (goods) moving through the region (10.5 bln tkm). At the same time the region with its very low unit cost of investment ($393/$m^2$) is very promising for investors. Variant 7 is featured by average levels of SEZ areas and transportation infrastructure developments. It is also considered moderate in terms of environmental friendliness and traffic safety. The unemployment rate of 14,0% in the region is relatively high and constitutes a serious social problem.

Variant 8 (V_8 - W) is located in the Western part of Poland. Total area of the region is above 29 000 km^2 and its population amounts to 3,9 mln people. The region is characterized by an average level of GDP per capita ($12 309) and thus represents the moderate level of economic development. Investment- and logistics-wise variant 8 is very attractive. It is featured by very low unit cost of investment ($395/$m^2$), the highest level of SEZ areas and very high overall volume of material flows (goods) moving through the region (more than 13 bln tkm). From social and infrastructural points of view variant 8 is considered to be satisfactory. The unemployment rate of 12,8% and the indexes of transportation infrastructure development are at the average levels. The region is also moderate in terms of environmental friendliness. Unfortunately, it is not very attractive in terms of traffic safety.

Variant 9 (V_9 - CS) is located in the Central-Southern part of Poland. Total area of the region is around 12 000 km^2 and its population amounts to 4,6 mln people. The region is highly industrialized (heavy industry) and thus it generates high level of GDP per capita (above $13 000) and a very high volume of material flows (goods) being moved through the region (above 14 bln tkm). The economic development and industrialization of the region have two impacts: positive – low unemployment rate of 9,4% and negative – high environmental pollution. The transportation infrastructure of this region is well developed. At the same time the traffic in this region is very heavy and generates high number of road accidents. The region, with its average unit cost of investment ($406/$m^2$) and higher than average level of SEZ areas, is considered to be investment – attractive.

Variant 10 (V_10 - S) is located in the Southern part of Poland. Total area of the region is slightly above 33 000 km^2 and its population amounts to 5,4 mln people. Variant 10 is diversified. Poor in the East and rich in the West. The region is featured by lower than average level of annual GDP per capita ($9 600) and moderate logistics attractiveness (volume of material flow around 12 bln tkm). The region's policy is to encourage investors and to pull money in. Thus, the unit cost of investment ($397/$m^2$) is low, while the level of SEZ areas is high. The overall unemployment rate of 12, 8% in the region represents the average level of the country. The region is also placed somewhere in the middle in terms of environmental friendliness and traffic safety. The transportation infrastructure of the region is well developed and it represents higher than average condition.

4.3. Consistent family of criteria

Based on methodological principles presented in section 3 the authors have proposed a set of 9 measures, denominated by C1, C2,…, C9 that includes criteria representing different aspects of evaluation and interests of different stakeholders. All 9 criteria are presented below.

- C1 - Condition of transportation infrastructure – [km/100km^2]. This maximized criterion is defined as a density of road and rail infrastructure in the considered region. It measures logistics accessibility of the region and transportation efficiency for distributing goods. The criterion is expressed as a ratio of the overall length of public roads and standard gauge railway lines and the total area of the region.
- C2 - Economic development – [$]. This maximized criterion is defined as an annual value of GDP per capita in the analysed region. It measures economic potential of a region, which is a critical factor influencing on investors' decisions concerning the placement of an investment.
- C3 - Investment cost – [$/$m^2$]. This minimized criterion together with criterion C5 measures investment attractiveness of a region and it is defined as an estimated unit cost of developing 1 sq. meter of the LC in the considered region. The aggregated cost includes: land purchase, territorial development, building materials, standard equipment and labour expenses.

C4 - Level of transportation and logistics competitiveness – [%]. This minimized criterion is defined as a percentage share of logistics service providers (transportation, forwarding and warehousing companies) operating in the region in the total number of such entities in the country. The criterion is minimized to guide the DM (investor) towards the selection of less competitive environments.

C5 - Investment attractiveness – [km^2]. This maximized criterion in combination with criterion C3 measures the overall attractiveness of a region. It is defined as a total area of all Special Economic Zones (SEZ) in the region. Thus, it helps to estimate potential benefits for the LC resulting from special rules, including income tax releases, VAT reductions, reduced land use and emploees' social benefits fees).

C6 - Transportation and logistics attractiveness – [mln tkm]. This maximized criterion measures the industry attractiveness of each region, expressed in terms of the total annual amount of load being transported in each region by all logistics service providers. Criterion C6 is calculated as a product of the total distance covered in a region by all carriers in a year and the total weight of load being carried on that distance.

C7 - Social attractiveness – [points]. This maximized criterion measures on the scale of 1-10 points the overall level of social satisfaction and challenges in each region. It is defined based on two major components: social status of the residents (unemployment rate) and their opportunities for education and career development (number of higher education institutions/ per 100000 residents).

C8 - Environmental-friendliness – [points]. This maximized criterion defines the environmental friendliness and the existing condition of environment in each region. It includes three components: level of noise, level of environmental pollution and the total area of protected territories (e.g. national parks).

C9 - Safety and security – [points]. This maximized criterion refers to both road and industrial as well as situational security. Criterion C9 is defined based on the following elements characteristic for the region: number of traffic accidents (fatal, injuries), number of industrial accidents per 1000 employees, number of crimes and offences (thefts, robberies, vandalism).

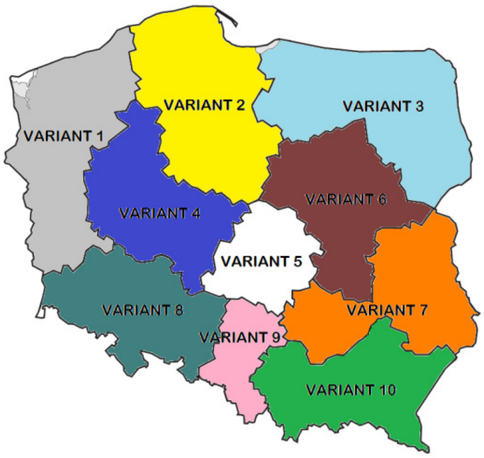


Figure 1. Potential regions (variants)

Table 1. Evaluation matrix for the compared variants

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Direction of preference	Max	Max	Min	Min	Max	Max	Max	Max	Max
Unit	km/ 100km^2	$	$	%	km^2	mln tkm	pts	pts	pts
Variant 1	90,3	11350	392	9,0	1110	9709	4,50	7,50	7,50
Variant 2	132,2	11558	421	12,0	1019	13379	7,17	6,50	4,50
Variant 3	98,0	9416	395	6,0	1176	6991	4,33	6,50	8,00
Variant 4	101,3	13275	443	9,0	312	11904	5,17	6,50	6,00
Variant 5	138,5	11939	402	6,0	606	7958	7,00	8,00	7,50
Variant 6	146,8	20049	424	18,0	284	15669	4,00	6,50	3,75
Variant 7	133,1	9396	393	7,0	900	10425	7,00	6,00	7,50
Variant 8	121,7	12989	395	10,0	2789	13275	8,00	7,50	5,25
Variant 9	222,7	13822	406	12,0	1733	14382	4,17	4,00	3,75
Variant 10	146,9	10131	397	13,0	2355	11653	7,00	4,50	4,75

4.4. Modeling of DM's and stakeholders' preferences

The model of the DM's and stakeholders' preferences has been constructed based on interviews and surveys carried out with representatives of: investors, local residents, local companies and logistics service providers. Initially, preferences of each individual, concerning the importance of the criteria and the sensitivity of each person with respect to the changes of the criteria values, have been determined. Afterwards individual preferences and expectations have been aggregated and transferred into one, coherent model of preference, characteristic for the Electre III/IV method. This model, presented in table 4, utilizes weights of criteria – w and thresholds of indifference - q, preference - p and veto – v, to differentiate variants between each other.

Table 2. Aggregated model of preferences of the DM and stakeholders

		C1	C2	C3	C4	C5	C6	C7	C8	C9
Weight	**w**	7,0	10,0	5,0	8,0	7,0	9,5	6,5	4,5	3,0
Thresholds	**q**	10	500	10	1,0	100	1000	0,5	0,5	0,5
	p	30	3500	30	5,0	500	3000	2,0	2,0	2,0
	v	70	7500	100	15,0	2000	7500	4,5	4,5	4,5

5. Computational experiments

The computational experiments have been carried out with the application of computer implementation of the ELECTRE III/IV method, whose algorithm has been presented in section 3.2. Computational experiments have been initiated by the construction of the evaluation matrix that contains data assessing all variants on all criteria (see table 1). Afterwards the aggregated model of preferences has been defined (see table 2).

As a result the concordance matrix, composed of the global concordance indicators, has been constructed (see figure 2a). These indicators define the degree of fulfilling the assertation that " a outrank b", based on the arguments supporting this statement (arguments "for"), only. Thus, taking, for instance, the example of variants V_8 and V_9, V_8 outranks V_9 with a global indication *C(a,b)*=0,85. At the same time the inverse indication that V_9 outranks V_8 is represented by *C(b,a)*=0,63. These figures can be interpreted as an indication that there are slightly more arguments supporting the assertion that V_8 outranks V_9. Similar reasoning can be carried out for all pair-wise compared variants.

In the next step of the computational procedure the credibility matrix, or in other words, the quantitative evaluations of the outranking relation has been generated (see figure 2b). This table contains degrees of credibility that define the overall support of the assertion "a outranks b". The degrees of credibility *d (a,b)* are equivalent to the global concordance indicator *C (a,b)* weakened by the discordance indexes $d_j(a,b)$ for each criterion *j*. They aggregate the arguments "for" and "against" the statement that "a outranks b". In the analyzed example of variants V_8 and V_9, there are no arguments that V_8 outranks V_9 overall [*d(a,b)* = 0], while there are some weak chances that V_9 outranks V_8 [*d(b,a)*=0,45].

Based on the credibility matrix the method established two preliminary rankings (complete preorders) using descending and ascending distillations (see figures 2d and 2e, respectively). In the former the ranking is constructed from the top down to the bottom, while in the latter in the inverse sequence from the bottom up to the top. The resultant of these two distillations is the final preorder (see figure 2f). The intersection of both distillations is the final ranking presented by the ranking matrix (figure 2c) and the final graph (figure 2g). In the final ranking the following situations – relations may occur: indifference – *I* – variants are indifferent and graphically placed in the same box; preference – *P* – variant *a* is preferred to *b*; a is placed above b on the graph; non-preference – P^- - variant *a* is not preferred to *b*, thus, *a* is placed below *b* on the graph; incomparability – *R* – variants are not linked (interconnected) on the graph. Using the same example of variants V_8 and V_9 one can see that they are incomparable, which is indicated by letter *R* in the ranking matrix (figure 2c) and placement of V_8 and V_9 in separated boxes on the final graph (figure 2g).

The final ranking indicates that the two incomparable variants V_8 and V_9 outperform the remaining regions. Being at the top of the ranking they become the most desirable solutions. Variants V_8 and V_9 represent: Dolny Slask plus Opole Regions and Slask Region, respectively. They are located in the Western and Central-Southern part of Poland. Based on the results generated in the ranking matrix one may conclude that both variants are equally good (8 indications P-preferred). Variant V_8 is characterized by low investment costs, huge area of SEZ-s, social convenience and environmental friendliness. Variant V_9 has the best transportation infrastructure, high volume of material flows (transported goods) and excellent GDP per capita.

Two variants V_3 and V_4 are placed at the bottom of the ranking, which clearly indicates that they constitute the least desired regions for placing LC-s on their territory. Variant V4 is featured by low investment attractiveness and moderate potential on several other characteristics, including: development of transportation infrastructure and logistic attractiveness. Variant V_3 is very poor in terms of its economic development. It is featured by the lowest levels of GDP per capita and material flows being moved through the region. The region faces severe social and infrastructural problems. Based on the presented analysis the authors recommend either variant V_8 or V_9 for placing the LC on their territory.

a) Concordance matrix

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_10
V_1	1	0.61	0.93	0.81	0.69	0.56	0.73	0.43	0.5	0.58
V_2	0.79	1	0.74	0.83	0.73	0.71	0.74	0.68	0.65	0.8
V_3	0.77	0.52	1	0.66	0.61	0.56	0.61	0.35	0.45	0.48
V_4	0.75	0.57	0.69	1	0.5	0.53	0.52	0.58	0.57	0.58
V_5	0.83	0.76	0.88	0.8	1	0.69	0.83	0.66	0.53	0.73
V_6	0.6	0.62	0.62	0.76	0.54	1	0.51	0.5	0.6	0.55
V_7	0.84	0.76	0.95	0.8	0.82	0.66	1	0.49	0.45	0.83
V_8	0.95	1	0.85	0.99	0.81	0.64	0.87	1	0.85	0.91
V_9	0.8	0.81	0.74	0.77	0.63	0.75	0.62	0.63	1	0.75
V_10	0.74	0.83	0.74	0.66	0.67	0.62	0.77	0.55	0.58	1

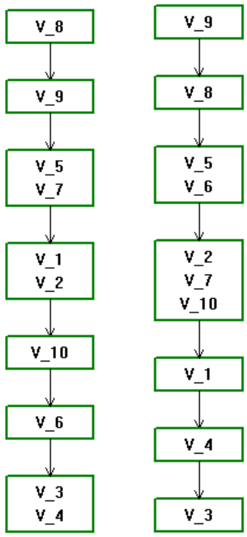
b) Credibility matrix

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_10
V_1	1	0.61	0.93	0.81	0.69	0	0.73	0.12	0	0.45
V_2	0.79	1	0.74	0.83	0.73	0	0.74	0.33	0	0.8
V_3	0.77	0.27	1	0.66	0.61	0	0.61	0.029	0	0.48
V_4	0.75	0.57	0.69	1	0.5	0.2	0.52	0	0	0
V_5	0.83	0.76	0.88	0.8	1	0	0.83	0	0	0.45
V_6	0.44	0.62	0.13	0.76	0.23	1	0.25	0	0	0
V_7	0.84	0.76	0.95	0.8	0.82	0	1	0.072	0	0.83
V_8	0.95	1	0.85	0.99	0.81	0.2	0.87	1	0	0.91
V_9	0.8	0.81	0.28	0.77	0.28	0.75	0.49	0.45	1	0.75
V_10	0.74	0.83	0.74	0.66	0.67	0	0.77	0.55	0	1

c) Ranking matrix

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_10
V_1	I	P^-	P	P	P^-	R	P^-	P^-	P^-	R
V_2	P	I	P	P	P^-	R	P^-	P^-	P^-	P
V_3	P^-	P^-	I	P^-	P^-	P^-	P^-	P^-	P^-	P^-
V_4	P^-	P^-	P	I	P^-	P^-	P^-	P^-	P^-	P^-
V_5	P	P	P	P	I	P	P	P^-	P^-	P
V_6	R	R	P	P	P^-	I	R	P^-	P^-	R
V_7	P	P	P	P	P^-	R	I	P^-	P^-	P
V_8	P	P	P	P	P	P	P	I	R	P
V_9	P	P	P	P	P	P	P	R	I	P
V_10	R	P^-	P	P	P^-	R	P^-	P^-	P^-	I

d) Descending distillation e) Ascending distillation



f) Final preorder

Rank	Alternative
1	V_8 V_9
2	V_5
3	V_6 V_7
4	V_2
5	V_1 V_10
6	V_4
7	V_3

g) Final graph

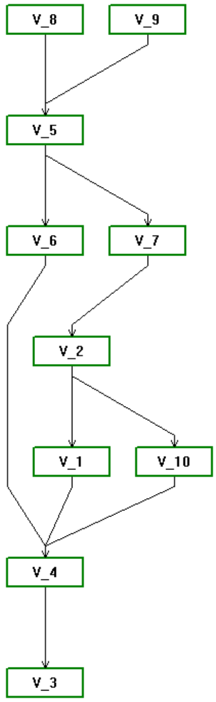


Figure 2. The results of computational experiments

6. Conclusions

As presented in this paper the selection of the location of the LC is a complex, multi-stage process. As indicated by the authors it can be split into two phrases, including: 1) the macro-analysis of the regions being the potential areas for placing the LC-s on their territory; 2) the micro-analysis of specific locations in the selected region. In this paper the authors have presented the first stage of this procedure, which has involved the definition of variants and the consistent family of criteria, modelling of the DM's and stakeholders' preferences and performing a series of computational experiments resulting in generation of the final ranking of regions. The authors have proved that multiple criteria nature of the LC location problem may induce a conflict of interests between the DM and stakeholders (interveners) and an effort must be put to find a compromise solution.

The original output of this research is as follows:

- Division of the LC location problem into two phases.
- Formulating the regions' evaluation problem as a multiple criteria ranking problem with the definition of an original family of evaluation criteria.
- Generating the ranking of the regions with the application of ELECTRE III/IV method.
- Proving the applicability of ELECTRE III/IV method to the analysis of the LC location problem.

The proposed methodology has a universal character and can be applied in selecting any location of the LC and any other elements of the logistics infrastructure, including warehouses, shopping centers, transportation hubs. After certain customization it can be also used in solving other categories of location problems.

From a practical point of view the results of this project can be summarized as follows:

– The best regions for placing the LC-s on their territory are variants V_8 and V_9. The first one is more attractive from an investor point of view, due to low investment cost, large SEZ areas as well as social and environmental friendliness. The second one has well developed transportation infrastructure and it is featured by high levels of economic development and logistics attractiveness.
– In the regions' evaluation process preferences of various stakeholders differentiate significantly. The interests of local residents focus on social, environmental and safety aspects, while investors, logistics operators and local companies consider primarily economic and market-oriented issues.

This research should be further extended and conducted in three areas, focused on:

- Formulating and solving the second sub-problem of the LC location problem. This second stage should involve the micro analysis and should be focused on selecting specific locations for the LC in the selected region.
- Extension and customization of the proposed approach towards other categories of the location problem, including the recognition of the best location for such infrastructural elements as: Park & Ride parking lots, passenger and cargo terminals, airports and harbors.
- Comparison of a two stage multiple criteria, ranking oriented methodology and multiple objective mathematical programming oriented approach of solving the LC location problem. The analysis of the results generated by both approaches could be very enlightening and should provide interesting indications on further research concerning the location problem.

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